EGG-FT-5273

# FUEL PLATE AND FUSION INSULATOR

# IRRADIATION TEST PROGRAM

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## DISCLAIMER

# DISCLAIMER

ABSTRACT

As the prices of fuel fabricating, shipping, and reprocessing continue to rise at rapid rates, research people look for alternate methods to keep their reactor fuel costs within limited funds. Extending fuel element lifetimes without jeopardizing reactor safety can reduce fuel costs by up to a factor of two. But to gain this factor, some fuel plate tests must be performed to the higher burnup to verify burnup fuel plate performance.

In this proposed test, fuel plates will

1. Be constructed to a maximum fuel loading which can be produced on a commercial basis

2. Contain a maximum boron content as used in ATR to reduce initial reactor reactivity

3. Will be loaded with $UAl_2$ to obtain higher uranium content and better operating performance over $UAl_3$.

One set of $UAl_3$ plates will be included as a baseline case. When this test program is completed, results are expected to provide the Missouri University and the Massachusetts Institute of Technology research reactors using aluminum fuel plates with the technical justification for using high burnup, long life fuel elements. Fuel cost savings at Missouri University Research Reactor (MURR) alone would be about $250,000 per year.

## FORWARD

The low-enrichment plate development program seeks to reduce enrichment levels in most research reactors by coupling an enrichment reduction with increased uranium weight over present loadings. But several university test reactors cannot continue present performance levels with reduced fuel enrichment. The Idaho National Engineering Laboratory (INEL) has the responsibility to DOE-ID of providing fuel elements for these reactors under the university fuel procurement Test, Research and Training Reactor (TRTR) program.

The planned irradiation test program combines a fuel plate burnup program with a fusion insulator irradiation program to meet the requirements of both programs at a considerable overall cost savings. Results from this program will provide:

1. These two research reactors with experimental results to justify high-level burnup of heavily loaded fuel elements at a considerable cost reduction to themselves and DOE. This will also assist the nation's nonproliferation efforts by reducing the number of fully enriched uranium shipments.

2. The fusion program with a radiation facility for damage measurements on numerous magnet insulator candidate materials.

The fusion work requires a hard neutron spectrum with absorbed doses of fast neutrons and gammas to be about one to one. The Advanced Test Reactor (ATR) I-holes meet the need for size and low gamma heating but lack the required fast neutron flux. Fuel plates arranged around the capsule region will provide the fast neutron flux and provide a dosage ratio required by this program. The remainder of the report will be limited to the discussion of the fuel plate irradiation program.

Support for a heavily loaded high burnup fuel plate irradiation program has been received from the Missouri University Research Reactor (MURR) and the Massachusetts Institute of Technology Reactor (MITR). This support is a result of the fuel cost savings to be realized from high burnup reactor core loading.

# ACKNOWLEDGEMENTS

We wish to thank Mr. G. W. Gibson for his help in the interaction of this program with the universities and for his helpful suggestions. Also, thanks to Mr. K. B. Anselmi for his program support.

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# INTRODUCTION

The Fuel Plate and Fusion Insulator Irradiation Test Program will be conducted under the Test, Research and Training Reactor (TRTR) Program by EG&G Idaho Inc. The test series will define the behavior of heavily loaded irradiated aluminide plate fuel during long-term reactor coditions, i.e., high burnup.

This report outlines the proposed test program as envisioned by EG&G Idaho Inc., and approved by both University of Missouri and Massachusetts Institute of Technology reactor managements. The objective of this test is to provide these reactor managers with experimental support data needed to request the use of higher loaded fuel elements to a higher burnup limit than is allowed at present.

# TEST PROGRAM

## Program Definition

At the meeting on March 27, and 28, 1980, the participating universities, the Department of Energy (DOE), the Nuclear Regulatory Commission (NRC), Atomics International (AI), and EG&G Idaho, Inc., met to formulate a test program which would provide each university reactor program with the required test data. A program matrix was generated as shown in Table 1. Five sets of plates were requested if the geometry could be arranged. Parameters in the test matrix were selected for highest probability of failure. Worst case would be low void percent, maximum boron content, high burnup, and high fuel loading. Since the void percent cannot be controlled in the fuel fabrication, plates with the lowest void percent will be selected from those fabricated and placed in the highest burnup positions. The boron content for all plates will be set at the same level as the maximum boron used in Advanced Test Reactor (ATR) fuel. Maximum burnup in this test will be about 3.3 x $10^{21}$ fission/$cm^3$, or twice what is presently allowed at the Missouri University Research Reactor (MURR). The 50 volume percent (V/%) test will be for the maximum V/% composition for which quality plates can be fabricated and above what the universities expect to use. Each test in Table 1 contains three plates. Each plate will have a different burnup. Burnup will vary about a factor of two from minimum to maximum burnup.

Estimated maximum burnup will be reached in 18 to 20 ATR 30-day cycles. All plates will be stored in the ATR canal until the end of test. They will be transferred to the hot cell in one shipment. Figure 1 is the tentative construction and test program schedule. Figure 2 is a detailed construction schedule leading to reactor insertion in the mid January shutdown. As is shown, fuel plate construction is on the critical path.

Twelve fuel plates will be grouped by three around a center capsule. All plates will be constructed to the same specification for reduced cost, but the V/% and dispersions will differ. Plate thicknesses will duplicate MURR and ATR fuel plates with a 0.020-in. core of fully enriched $^{235}U$. Plates will be 1 in. wide by 0.050 in. thick and constructed of 6061 aluminum. The fuel core will be approximatly 0.8 in. wide and 10-1/2 in. long.

The fuel plates will contain a total of about 70 g of $^{235}U$ (an order of magnitude below a minimum optimum critical mass). Because the I-holes are located outside the shims, insertion of fuel in this position will have little effect on the core reactivity. The ATR I-hole thermal flux will produce the fuel plate temperatures near what is experienced in the MURR and the Massachusetts Institute of Technology Reactor (MITR). Results of burnup tests should be directly applicable to these two reactors.

## $UAl_2$ Versus $UAl_3$ Fuel Core Matrix

Considerable radiation testing has been done with $UAl_x$ powder in which $UAl_3$ is the principal crystalline constituent; and several years of operational experience at ATR and other reactors has justified the MURR maximum burnup of $1.8 \times 10^{21}$ fissions/cm$^3$. The ATR burnup limit has been extended in steps to a fission density of $2.3 \times 10^{21}$ fissions/cm$^3$ in a 62.8 wt% $UAl_3$ core. A recent report by Beeston et al.,[1] indicates that an extention to $2.7 \times 10^{21}$ fissions/cm$^3$ of core is possible.

The fuel powder composition which is predominantly $UAl_3$ was orginally chosen since the powder can be prepared in air. $UAl_2$ powder is more pyrophoric than $UAl_3$. Some work has been done by Dienst et al.,[2] at Karlsruhe on irradiation behavior of $UAl_2$-Al and $UAl_3$-Al dispersion fuels for thermal high flux reactors. Although they did not study the burnup range of our required fuel loading, data strongly suggest that for high loaded, high burnup fuel plates, $UAl_2$-Al dispersion performs considerably better than $UAl_3$-Al.

The density of the $UAl_x$ powder now used is 6.2 g/cm$^3$ with a uranium content of 71.5%. Therefore, the uranium content of $UAl_x$ powder = 6.2 g/cm$^3$ x 0.715 = 4.43 g/cm$^3$. The uranium content[3] of $UAl_2$ is 6.64 g/cm$^3$ or 50% higher. However, to avoid the formation of metallic uranium the target uranium content will be 80%, slightly hypostoichiometric. At 80%, the uranium density is calculated to be 6.26 g/cm$^3$. To get the same uranium content when $UAl_2$ powder is substituted for $UAl_x$ powder until uranium content is 80%, we get

$$\frac{4.43}{6.26} \times 100 = 71\% \qquad (1)$$

i.e., we will use 29% less to achieve the same uranium density fuel powder.

The recent rolling test program at Atomics International[4] (AI) indicates current technology can be used to produce quality fuel plates on a production line basis with fuel cores containing up to 50 volume percent (V/%) $UAl_x$. The uranium concentration for a 50 V/% conventional fuel core is 2.22 g/cm$^3$ (0.5 x 4.43). If the $UAl_x$ powder is replaced by $UAl_2$, the uranium concentration can be increased to 3.13 g/cm$^3$ (0.5 x 6.26).

However, MURR and MITR fuel plates are currently being made with a uranium content of 1.6 g/cm$^3$ or about half the possible fuel content limit. Therefore, by using the recent AI rolling data and $UAl_2$ powder, the uranium content in the plates can be increased from the present value by the amount

$$\left(\frac{3.13}{1.6} - 1.00\right) \times 100 = 95\% \; . \qquad (2)$$

This increase will be important where long life elements are desired although some reactors at present may not be able to take full advantage of the full 95% due to excess reactivity limitations.

Although $UAl_2$ is more pyrophoric than $UAl_3$, it is believed that fabrication techniques used at AI are compatible with either dispersion. The glove boxes at AI use an argon atmosphere with a maximum oxygen content of 4%. This burnup test will confirm the performance of high weight percent uranium loadings at high burnup.

## Fuel Plate Fixture

The twelve plates will be held at the reactor center line and spaced 0.087 in. apart, i.e., the same as university and ATR fuel element plates. The fixture will be kept in the highest flux ATR I-hole each cycle. Figure 3 is of the ATR core showing location of the I-holes. The plates will be positioned in a square array similar to that depicted in Figure 4. The fixture will extend above the core for ease in removal. Integrated fluxes for both thermal and fast neutrons will be determined from foils located within the capsule. The fixture will limit and distribute the water cooling needed to provide the right cooling environment. At completion of the test, the fixture will be transported by cask to the hot cells for plate removal. The fixture will be stored in the ATR canal for 1 year after termination of this program in case further plate testing is needed.

## Neutronic Calculations

Neutronic calculations are required for both initial design and burnup. Using the existing ATR two-dimensional diffusion code PDQ and an overlay of the fuel plate fixture in one I-hole, fission rates and associated heating values will be used for thermal analysis and calculated operating fuel plate temperatures. Additional PDQ calculations with RZ corrections and flux monitors will provide burnup numbers for each cycle on each fuel plate.

## Funding

This is a jointly funded program as shown in Table 2. The University of Missouri will fund AI for the fuel plate fabrication and inspection. The fusion program will provide program management, reporting, and a portion of the canal operation costs for a total of $40,000. The remaining funding will come from the TRTR program. Table 3 shows a breakdown of costs by year.

FUEL PLATE CONSTRUCTION

## Plate Specifications

Plate dimensions were selected to fit the ATR I-hole configuration and to provide the plate area required for testing. Thickness of plates and cores and plate construction methods were selected to match the MURR and ATR fuel. Extrapolation of the test data to a 0.060-in. plate will provide MIT with the required supporting data for extended fuel burnup in the MITR.

As per the EG&G Idaho, Inc., fuel plate drawing number 414489, the finished plates will measure 1.000 $\pm$ 0.005 in. x 12.50 $\pm$ 0.03 in. x 0.050 $\pm$ 0.001 in. The fuel core dimension will be approximately 0.8 in. x 10.5 in. A 3/8-in. hole centered in the top end of each plate will provide a means for individual plate removal in the canal or hot cell.

## Core Material Specifications

The uranium-aluminide powder will be prepared by AI, and fuel plates will be fabricated according to the Technical Specifications Document ES-50607 with attachments. The Technical Specifications are included here in the appendix. The Uranium-235 enrichment shall be 93.0 $\pm$ 1.0 wt% for all batches. The metal impurities are not to exceed 0.3%, with no individual impurity to exceed 600 parts per million (PPM). The $^{235}U$ and chemical compositions as well as impurities will be measured and recorded in a certified report.

The finished ground and sized uranium-aluminide powder as determined by X-ray diffraction shall contain at least 70 wt% $UAl_2$ or $UAl_3$ as required for plate composition. No free metallic uranium will be present in any powder sample. Particle size shall be predominantly -100, +325 U.S. Standard mesh with up to 25 wt% of the material being -325 U.S. Standard mesh.

## Quality Control and Inspection

Non-destructive testing (NDT) inspections for non-bond and minimum cladding thickness will be according to, and meet the acceptance criteria of, the ATR Fuel Element Specification IN-F-9-ATR, Rev. 5 and Associated document.

## FUEL PLATE EXAMINATION PROGRAM

The purpose of the three part examination program for these sample fuel plates is to detect the changes which take place as a result of inpile radiation exposure. Selection of the tests and property measurements is based on the likely changes anticipated. It is essential to have good preirradiation characterization of sample plates in order to detect the changes which have occurred.

When uranium fissions, the fission products occupy more volume than the original uranium. If these fission products are not accommodated in the fuel core, they will cause the fuel plate to swell. This swelling is detected by water immersion measurement techniques employing the Archimedes principle. The accuracy of these data in terms of plate density is 0.01 $g/cm^3$.

Some of the fission products are gaseous. These gaseous atoms may agglomerate in the fuel particles and exert a pressure. The pressure is resisted by a shell of aluminum matrix material. At some threshold temperature, the matrix material will rupture causing blistering of the fuel plate. This condition is purposely produced as part of the test procedure by postirradiation, incremental heat treatments. The incremental heat treatments will be continued until blistering occurs. The center third of each plate will be used for this portion of the destructive examinations. A flow chart showing the examinations to be conducted is shown in Figure 5. Details of the examinations are discussed below.

## Preirradiation Examination

All fuel plates will be inspected to the same criteria used for the plates in the ATR fuel elements at AI prior to shipment to INEL. In addition, prior to the plates being loaded into the fixture at INEL, they will be examined on both sides for minor surface imperfections, and all defects will be recorded for comparison after irradiation. Minor surface imperfections are those which pass the plate technical specifications and are of a size or nature that under long-term irradiation might propagate a failure. Photographs will be taken of both sides. Any imperfections which are considered serious should be photographed at sufficient magnification to characterize the defect. Weight, volume, and multiple thickness measurements will also be recorded.

## Interirradiation Examination

When it has been determined that the burnup in any plate has exceeded a maximum burnup density of $3.0 \times 10^{21}$ fissions/$cm^3$, as determined by flux monitors and physics calculations, the fixture will be removed from the I-hole during one reactor shutdown and placed on the ATR Canal working platform. The top of the fixture will be removed and fuel plates back lighted. A visual examination will be made to locate any surface blisters. If any plates are found blistered, they will be replaced. The fixture will be reassembled and placed back in the ATR I-hole prior to startup.

## Postirradiation Examination

### Visual and Photographic

Both surfaces of each plate will be visually and photographically examined. Typical surface defects such as oxides, discoloration, handling marks or scratches, and stains will be photographed. The photographic examinations will be compared with the unirradiated examinations. Surfaces should be examined for pitting, blisters, and oxide spalling.

## Dimension

The plates will be weighed, and the dimensions will be determined. The oxide coatings will be measured using eddy current techniques.

## Gamma Scans

Gross gamma and spectral gamma scans will be conducted on all plates. One axial scan along the center of each plate will be made using a vertical collimator slit; transverse scans using a horizontal collimator slit will be made at two axial locations.

## Density Determination

Density values will be measured by immersion techniques on all plates individually, before and after chemically stripping the surface oxide. The oxide stripping solution should consist of 20 g of $Cr_3$ and 35 $cm^3$ of 85% phosphoric acid added to one liter of distilled water. Time required for oxide stripping is about 10 min. in the boiling solution.

## Plate Sectioning

The plan for marking and sectioning the plates is shown in Figure 6. All twelve plates will be sectioned in the same manner. Plates should be marked as shown before sectioning begins. Shearing and/or punching may be used to section the plates.

## Blister Annealing Evaluation

The twelve blister samples (the center section of each plate) will be used for this test. The samples will be heated starting at 535 K for 30 min. increments of 30 K until blistering (detection visually) occurs. The plates are to be inspected after each increment until blistering occurs. Each plate will then be photographed. A correlation between burnup and higher blister temperature will be determined and plotted.

## Metallography

Two samples from each of the twelve plates will be used for metallography. They are to be purposely removed from the upper and lower ends of fuel core (dog boned ends).

The metallography will be examined at 50X, 200X, and 500X for evidences of irradiation effects in the microstructures. The microstructures will indicate the percentage of the core void volume which has been filled at this irradiation. Porosity from gaseous fission products is not visible at these magnifications but core cracking, due most likely to shearing, will be visible. If some doubt exists as to the source of core cracking, additional samples will be cut out wth a diamond saw to verify this behavior. The shearing process will be used since it produces less contamination during sample preparation. The microstructures will be examined for abnormalities and changes due to irradiation and diffusion such as matrix reaction with the $UAl_x$ fuel and $UAl_x$ phase changes. Microstructures of differing fission densities should be compared and noted.

## Hardness and Thickness Measurements

One metallography sample from each plate will be measured for microhardness of the cladding, core, and matrix. The cladding and core thickness will be measured from the microstructure at a power of 50X.

## Burnup Analysis

Two burnup samples, numbers XXXA and XXXD, are available for burnup analyses. The highest and lowest gamma intensity areas from each composition will be analyzed for burnup. From these values, the gamma scans can be calibrated to give burnup versus position for all plates in each test. Neutron fluence and burnup will be calculated using the PDQ four energy group program through the radiation history of the plates.

Flux monitors removed each cycle from the capsule will be used to benchmark the PDQ burnup results. The time points will be chosen to represent the fuel plates at xenon-equilibrium conditions during irradiation.

Measured burnup data from the core burnup punches will be done by the Idaho Chemical Processing Plant (ICPP) Projects Section. Krypton and xenon analyses will also be performed by them. Burnup analyses will be made by five different methods:

1. By the sum of $^{145}Nd$ and $^{146}Nd$ which is considered the most accurate

2. By $^{133}Cs$

3. By $^{137}Cs$

4. By $^{148}Nd$

5. By uranium isotopic.

The separate techniques should give burnups which agree within 5% after adjustment for the different techniques to confirm the validity of the analyses.

Calculated Core Swelling

The core swelling may be determined from three measurments:

1. The increase in core thickness

2. The decrease in density

3. The gas content in conjunction with metallography and certain assumptions regarding bubble size.

Using the core thicknesses measured on the metallography samples, the density decrease can be calculated for (1) above. For (2) above, density values can be measured before and after the oxide is stripped from the samples. The density decrease can be calculated from the core-plus-cladding weight (density of Al = 2.702 g/cm$^3$) and the core-plus-cladding volume. For (3) above, the swelling may also be calculated from the gas content if bubble size and density are measured.

## Conclusions

An evaluation will be done by the Fuels and Materials Division of all the visual, nondestructive, and destructive analysis work. Each of the failure modes will be addressed separately. The data will be used to postulate an expected incipient failure radiation level upon further irradiation to an identifiable increment of burnup. Results should be compared with previous results of work done with $UAl_3$ at INEL by Beeston,[1] and work on $UAl_2$ and $UAl_3$ dispersions by Dienst.[2] All results and conclusions will be included in the final report.

## Fuel Canning

All scrap plates and cutting will be collected, sealed in a canister, and stored in the ATR Canal for later processing at ICPP.

# FINAL REPORT AND RECOMMENDATIONS

A final report will be prepared during fuel plate post examination and completed soon after program completion. This report will include the specimen irradiation evaluations and conclusions along with all data and analyses. The conclusions will include recommended maximum fuel burnup, operating temperatures, fuel plate construction use of $UAl_2$ dispersion, oxide buildup, and expected failure rates.

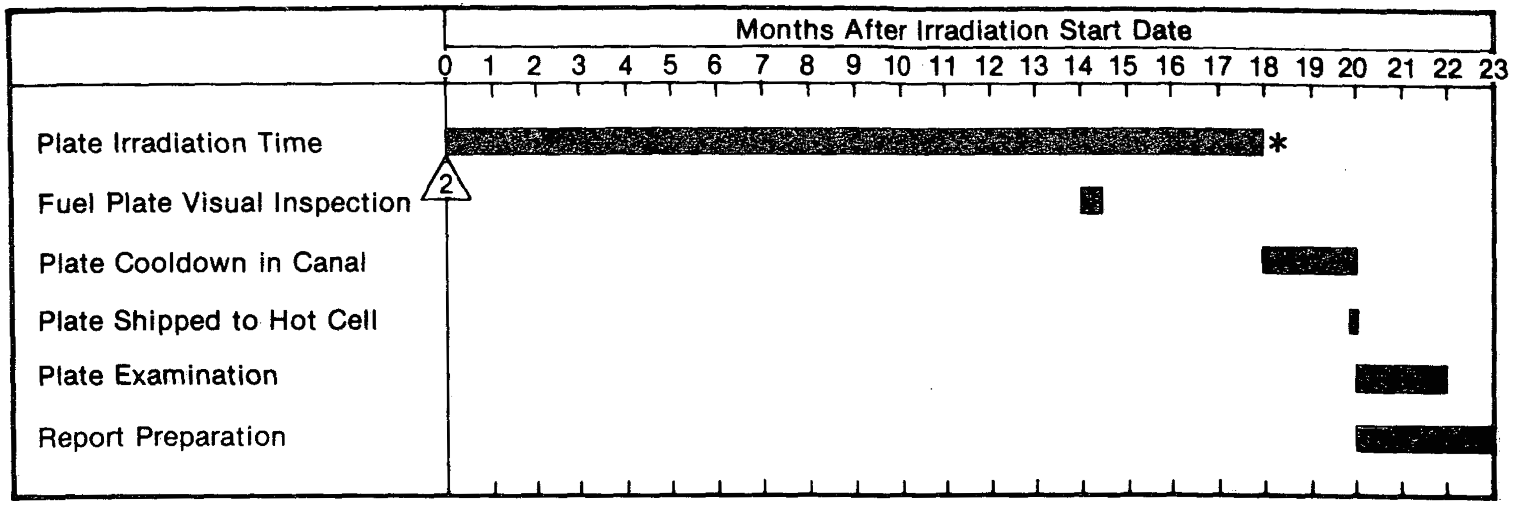
## REFERENCES


1. J. M. Beeston et al., "Development and Irradiation Performance of Uranium Aluminide Fuels in Test Reactors," Nuclear Technology, 49, 136-149, 1980.

2. W. Dienst, S. Nazar'e, F. Thummler, "Irradiation Behavior of $UAl_x$-Al Dispersion Fuels for Thermal High Flux Reactors," Journal of Nuclear Material, 64, 1-13, 1977.

3. G. W. Gibson, "The Development of Powdered Uranium-Aluminide Compounds for Use as Nuclear Reactor Fuels," IN-1133, Idaho Nuclear Company, 1967.

4. D. Atkins, "Results and Evaluation of Producibility Studies Using $UAl_x$ for Low Enriched Fuel Plates," N275TR000001, Rockwell International, 1979.

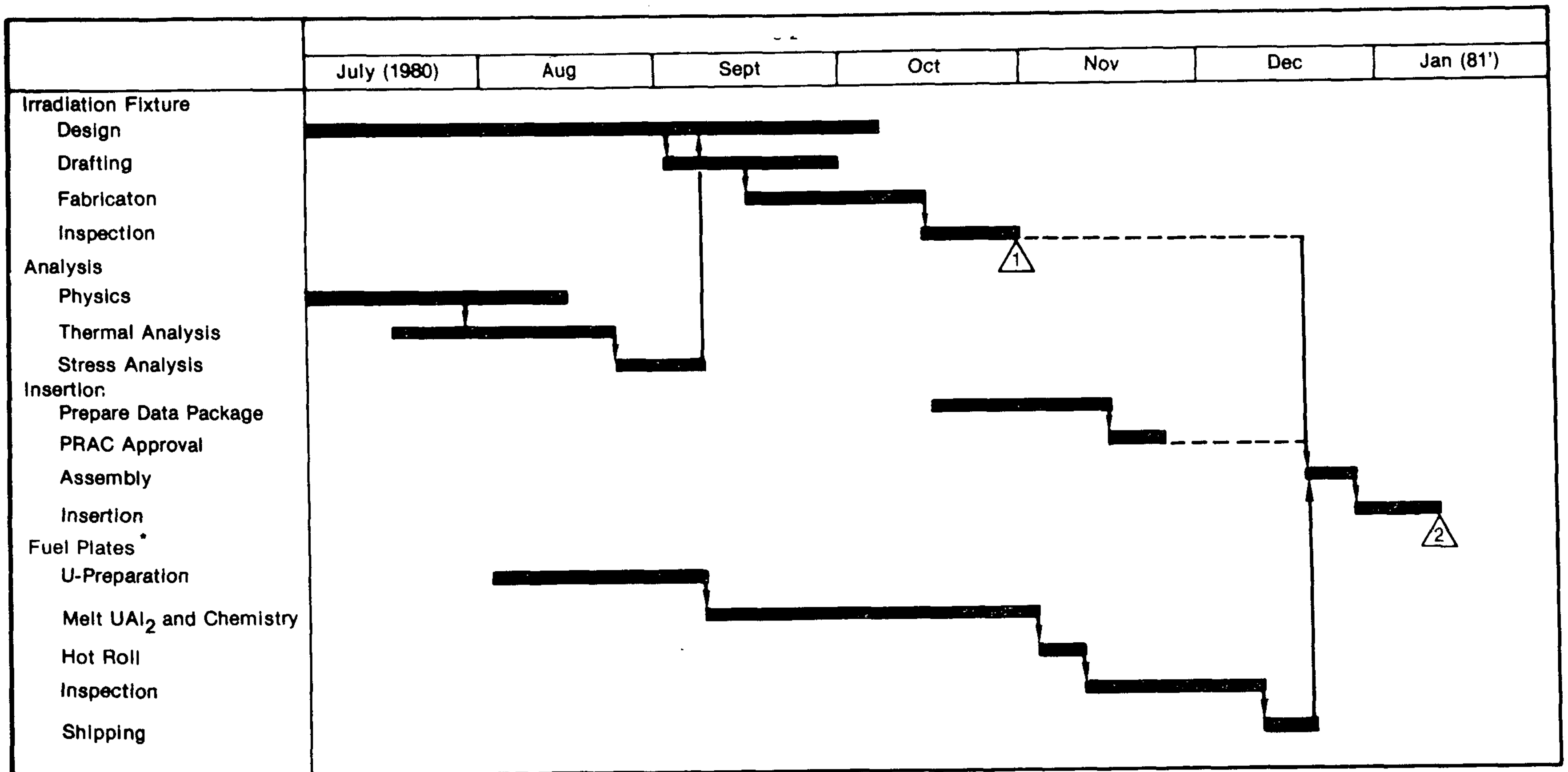



* An estimate of 18 to 20 reactor cycles (30 day cycles) will be required to complete burnup

INEL-A-16 523

2 Start of irradiation milestone

Figure 1. Construction and test program schedule.




* Fuel Plates Being Procured From Al by the TRTR Program

1 Completion of Hardware Milestone

2 Start of Irradiation Milestone (Contingent on Fuel Plate Arrival from Al)

Figure 2. Detailed construction schedule.

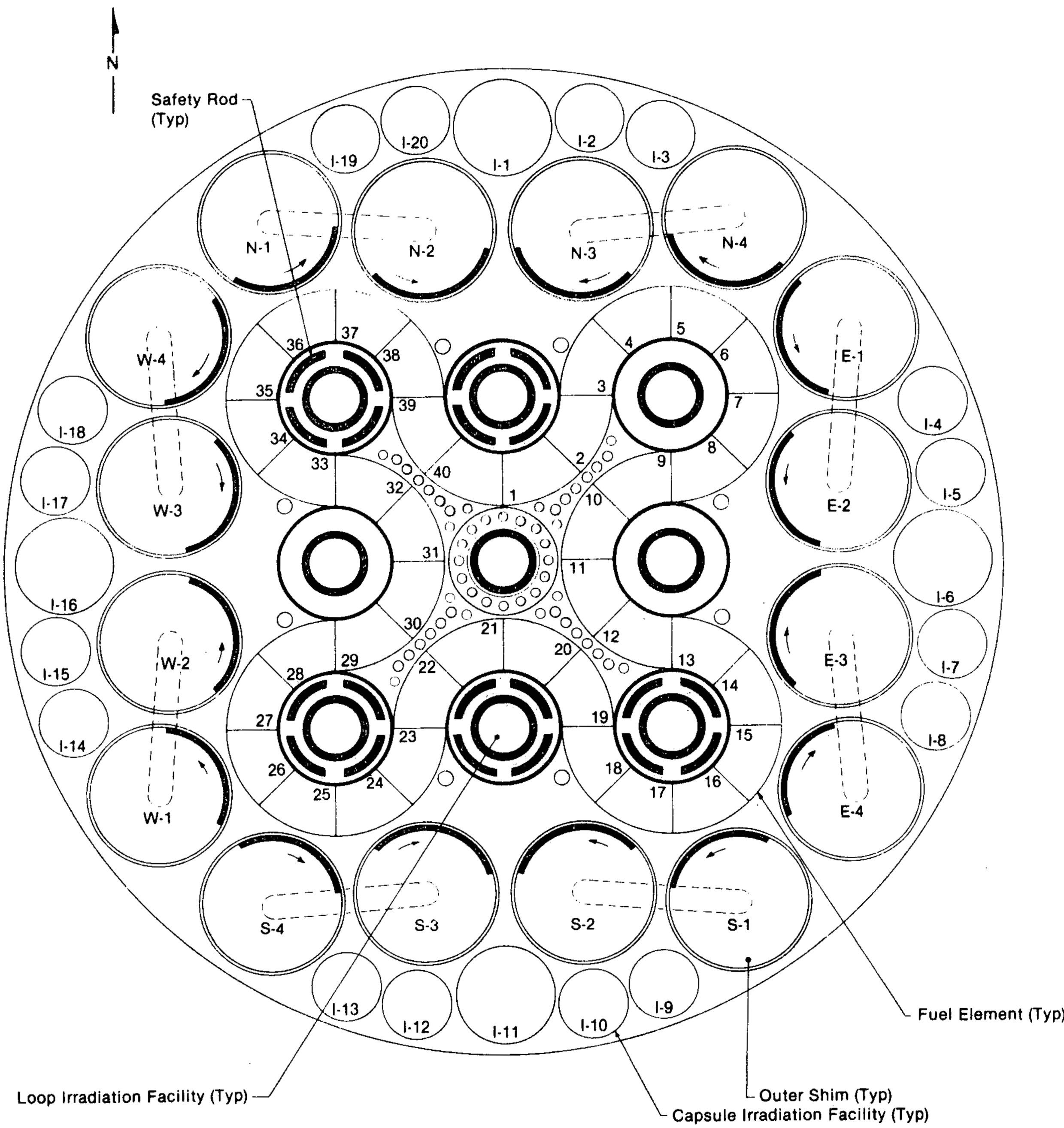



Figure 3. ATR reactor core configuration.

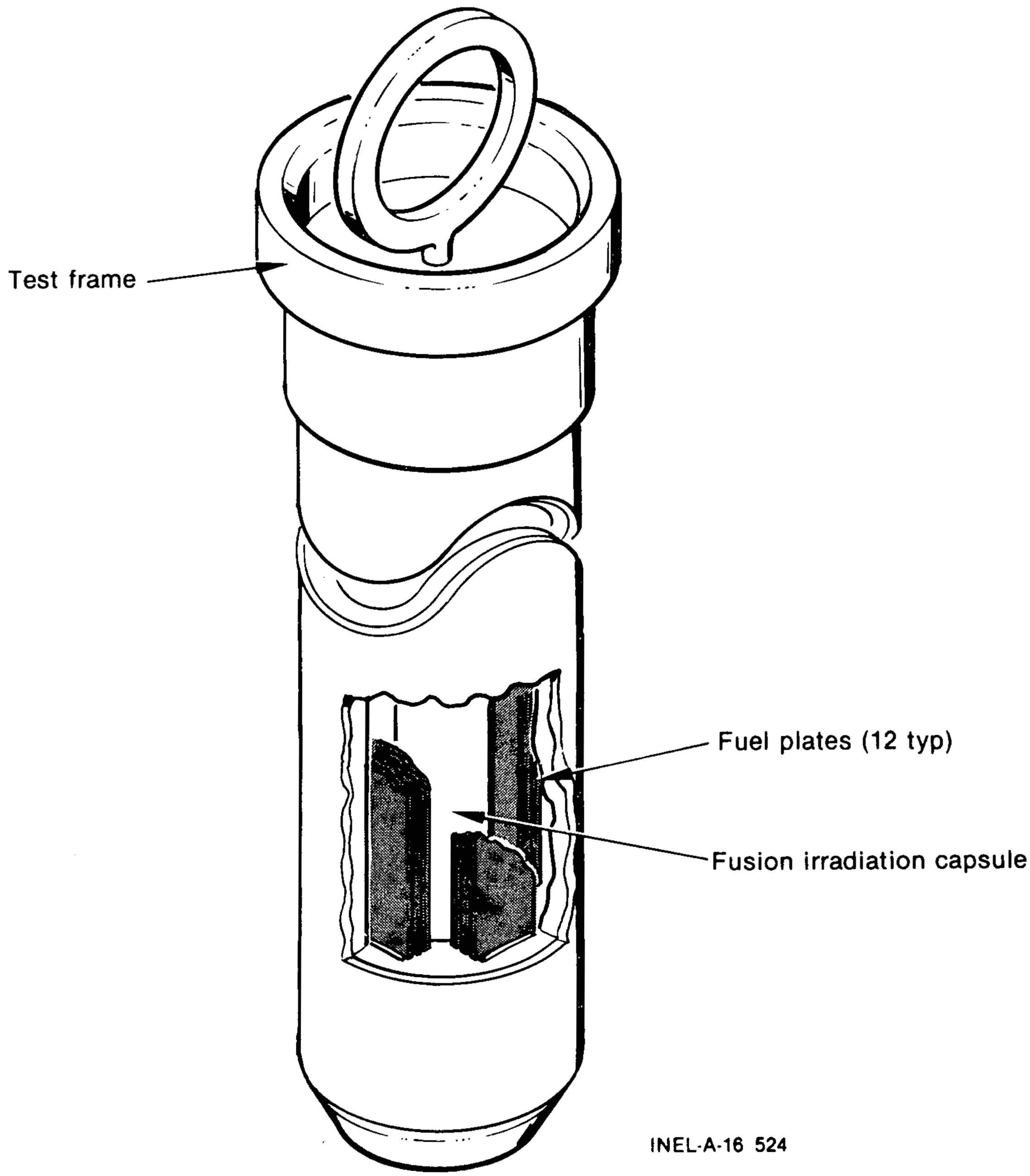



Figure 4. Fuel plate test configuration.

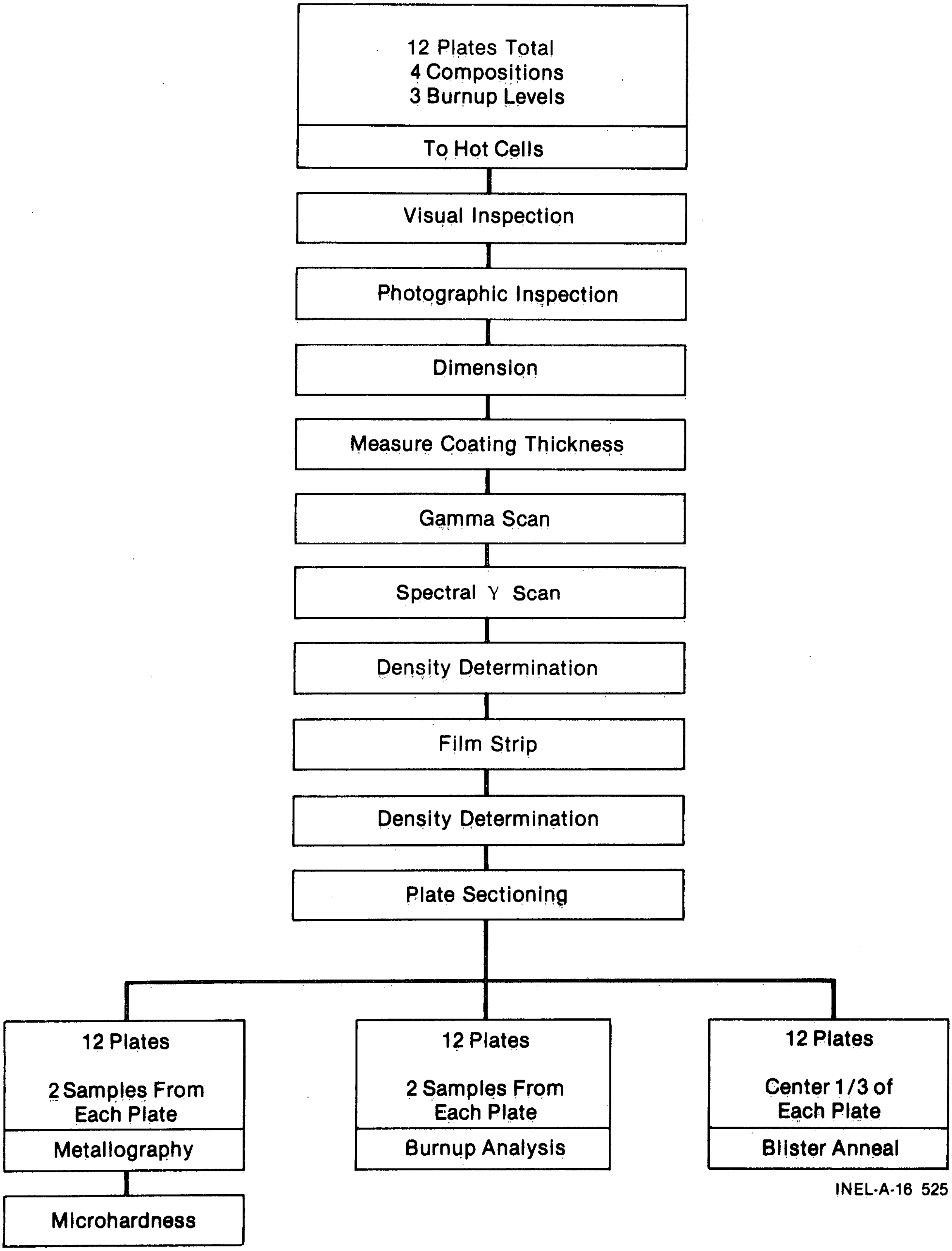



Figure 5. Plate examination flowchart.

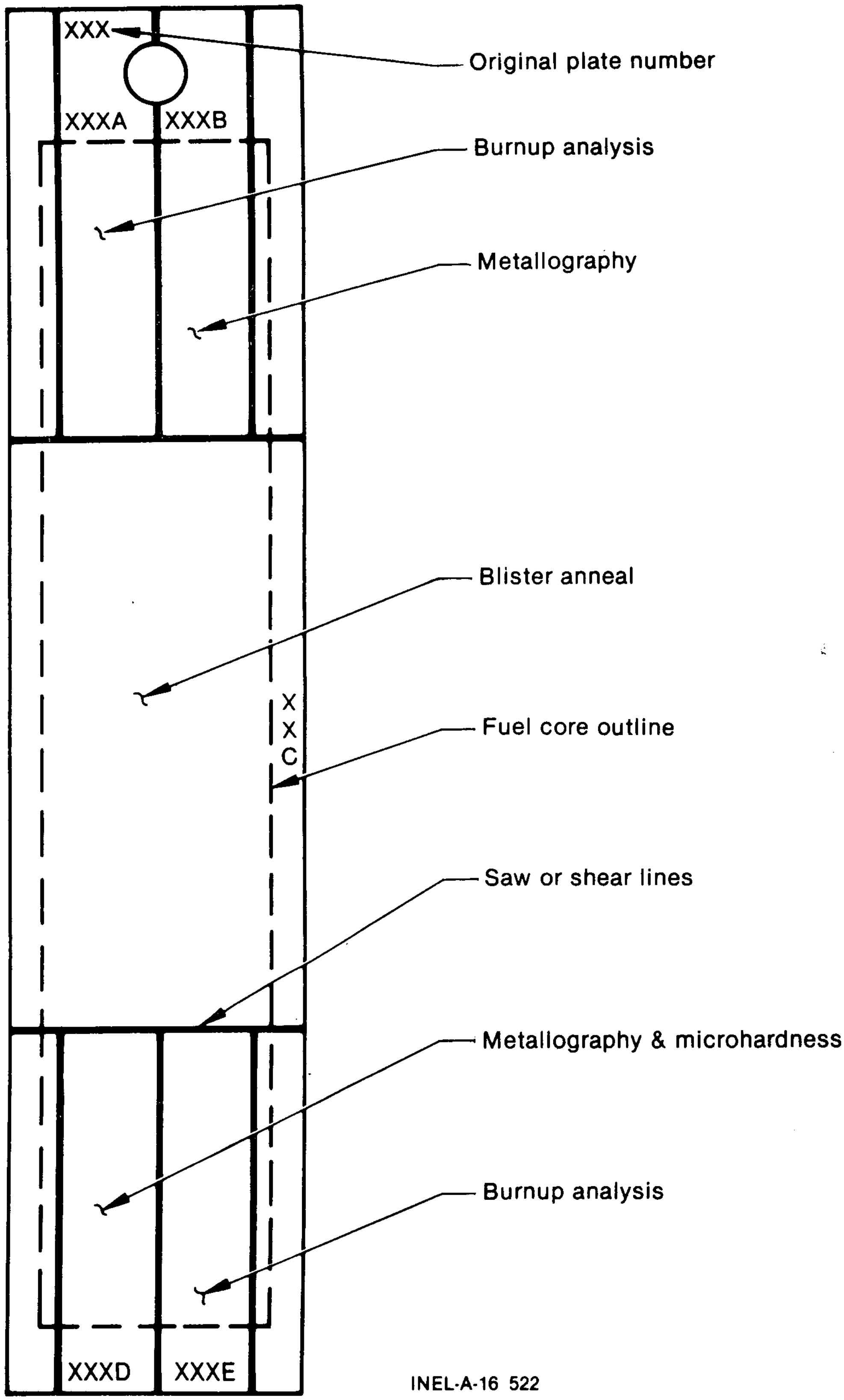



Figure 6. Plate section detailing.

TABLE 1. TEST SPECIFICATION

| Number | Compound | U ($g/cm^3$)[a] | $UAl_x$ (core volume %) | Estimated Maximum Burnup ($fissions/cm^3$) | $g\,^{10}B/g\,^{235}U$ |
|---|---|---|---|---|---|
| 1 | $UAl_2$ | 2.51 | 40 | $2.9 \times 10^{21}$ | 0.00266 |
| 2 | $UAl_2$ | 2.82 | 45 | $3.0 \times 19^{21}$ | 0.00266 |
| 3 | $UAl_2$ | 3.13 | 50 | $3.3 \times 10^{21}$ | 0.00266 |
| 4 | $UAl_3$ | 2.22 | 50 | $2.7 \times 10^{21}$ | 0.00266 |

a. These are theoretical values. Expected values may differ slightly due to other crystalline forms of $UAl_x$ in the core material.

TABLE 2. PROGRAM COST BREAKDOWN

| Task | Fusion Cost ($K) | TRTR Cost ($K) | MURR Cost ($K) | Total Cost ($K) |
|---|---|---|---|---|
| Design, construction, and reviews of fixture with contingency | -- | 60 | -- | 60 |
| Physics calculations | -- | 30 | -- | 30 |
| Fuel plate technical specifications | -- | 10 | -- | 10 |
| Program management | 25 | -- | -- | 25 |
| Fuel plate construction | -- | -- | 45 | 45 |
| Fuel plate testing | -- | 60 | -- | 60 |
| Reporting | 10 | 10 | -- | 20 |
| Canal operations | 5 | 20 | -- | 25 |
| | 40 | 190 | 45 | 275 |

TABLE 3. FISCAL YEAR COST BREAKDOWN

| Fiscal Year | Fusion Program Costs ($K) | TRTR Program Costs ($K) | University of Missouri Costs ($K) | Total Costs ($K) |
|---|---|---|---|---|
| 80 | 15 | 70 | 0 | 85 |
| 81 | 10 | 30 | 45 | 85 |
| 82 | 15 | 90 | 0 | 105 |
| TOTAL | 40 | 190 | 45 | 275 |

APPENDIX

EXTENDED LIFE ALUMINIDE
FUEL PLATES

EG&G Idaho, Inc.

ES — 50607 A
DATE — Nov. 5, 1980

# SPECIFICATION

EXTENDED LIFE ALUMINIDE FUEL PLATES

Approved for Release:

R. H. Ising

R. H. Ising
Specifications and Standards
EG&G Idaho, Inc.

EG&G Idaho, Inc.

FORM EG&G-1624
(Rev. 02-79)

# DOCUMENT APPROVAL SIGNATURE SHEET

| TYPE OF DOCUMENT | DOCUMENT NO. |
|---|---|
| Specification | ES-50607 A |

TITLE

EXTENDED LIFE ALUMINIDE FUEL PLATES

PREPARED BY D. G. Newton DGN — EXT. 8121

ORIGINATED BY D. G. Newton DGN — EXT.

| APPROVAL AND REVIEW SIGNATURES | ORGANIZATION | DATE |
|---|---|---|
| J. D. Stearns J. D. Stearns | Quality Division | 10-30-80 |
| L. S. Richardson L. S. Richardson | Materials Science Branch | 11/3/80 |
| L. G. Miller L. G. Miller | ELAF Program Manager | 11-4-80 |
| D. M. McGinty D. M. McGinty / DGN per telecon | University of Missouri | 10-30-80 |
| L. Clark, Jr. L. Clark / DGN per telecon | Massachusetts Institute of Technology | 10-30-80 |
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FIGURE



ATTACHMENTS

1. SCOPE

1.1 This specification details the materials, components, testing, inspection, and quality control requirements for the fabrication of extended life uranium aluminide experimental fuel plates.

1.2 Definitions. For the purpose of this specification, the following terms are identified: (Capitalization shall denote the use of a defined term).

1.2.1 Batch. A quantity of $UAl_x$ produced in one operation.

1.2.2 Blended. To mix or mingle constituents of a Batch.

1.2.3 Cladding. The aluminum covers bonded to the Fuel Core and the Picture Frame.

1.2.4 Dogbone Area. Region of the Fuel Core within one and one-half inches from its ends, where thickening can occur during the rolling process.

1.2.5 Fabricator. The primary vendor selected by EG&G Idaho, Inc., to manufacture the Fuel Plates.

1.2.6 Fuel Core. The uranium-bearing region of each Fuel Plate.

1.2.7 Fuel Plate. An assembly consisting of a Fuel Core enclosed in an aluminum frame and cladding.

1.2.8 In-Process Controls. Inspections and tests made during Production to ensure that the Manufacturing processes, equipment, and personnel are producing a product meeting specified requirements.

1.2.9 Lot. A group of two to twelve sequentially numbered Fuel Plates of a given composition, handled as a unit traceable to a common processing step.

1.2.10 Manufacture(ing). All fabrication, assembly, test, inspection, and quality control processes.

1.2.11 Picture Frame. The window-shaped aluminum frame which holds the Fuel Core.

1.2.12 Purchaser. EG&G Idaho, Inc.

1.2.13 Rejection. Materials, parts, components, or assembly products which will not be accepted as part of the contract requirements of this program because of noncompliance with this Specification.

1.2.14 Specification. All parts and supplements of this document, its references, drawings, and standards.

1.2.15 Sub-tier Supplier. Any vendor selected by the fabricator to furnish materials, services, or manufactured parts to the products.

1.2.16 $UAl_x$. An intermetallic compound of uranium and aluminum used as the active ingredient in the Fuel Core.

2. APPLICABLE DOCUMENTS

The following documents are a part of this Specification:

2.1 Federal Standards. Title 49 Code of Federal Regulations - Transportation.

2.2 Technical Society Standards.

| | |
|---|---|
| ASTM B-209 | Aluminum Alloy Sheet and Plate |

2.3 Drawings (EG&G Idaho, Inc.).

| | |
|---|---|
| 414489 | Extended Life Aluminide Fuel Plate |

2.4 Reactor Development and Technology (RDT).

| | |
|---|---|
| RDT F2-4T | Quality Verification Program Requirements |
| RDT F3-2T | Calibration System Requirements |
| RDT F5-1T | Cleaning and Cleanliness Requirements for Nuclear Components |

2.5 Specifications (EG&G Idaho, Inc.).

| | |
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| Attachment I | Determination of Fuel Core Voidage |
| Attachment II | Requirements for Radiographing Fuel Plates |
| Attachment III | Specification for Aluminum Powder for the Fuel Core Matrix |
| Attachment IV | Specification for Enriched U-Metal Used for Synthesizing Uranium Aluminide |

| | |
|---|---|
| Attachment V | Specification for Aluminum Stock Used for Synthesizing Uranium Aluminide |
| Attachment VI | Specification for Uranium Aluminide Powder for ELAF Fuel Plates |
| Attachment VII | Specification for Boron Carbide Powder for ELAF Plates |

3. REQUIREMENTS

3.1 Documentation. Three copies of the following items shall be supplied to the Purchaser prior to initial fabrication of the Fuel Plates, for review and approval:

(1) All shop drawings and procedures to be used in the fabrication and inspection of the Fuel Plates

(2) Integrated manufacturing and inspection test plan.

(3) A detailed procedure as to the manner by which the Fabricator proposes to assign Fuel Plate U-235 and B-10 contents. Included in the procedure shall be sampling, analytical and quality control procedures, and a statement as to the estimated accuracies of the assigned U-235 and B-10 contents.

(4) Procedure for void fraction determination in compliance with Attachment I.

3.2 Manufacturing Requirements

3.2.1 Fuel Plates shall be hot rolled after being preheated at 925 ± 15°F for at least one hour. Reheating between passes shall be at 925 ± 15°F for at least 5 minutes. The hot-rolling process shall leave sufficient excess thickness to permit at least 5% cold reduction.

3.2.2 Following hot rolling Fuel Plates shall be blister tested in accordance with 5.6.

3.2.3 Fuel Plates shall be cold rolled at least 5%.

3.2.4 Following cold rolling, Fuel Plates shall be annealed at 770 ± 15°F for 2 to 3 hours and furnace cooled at a rate not to exceed 50°F/h to below 500°F. Cooling below 500°F may be in room air.

3.2.5 Before packaging, the Fuel Plates shall be pickled by submerging them for 5 to 15 minutes in an aqueous solution of about 25-35% 1.42 specific gravity $HNO_3$ at 140-160°F followed by spray rinsing with deionized water, immersion rinsing in deionized water at 140-160°F, and air drying.

3.3 Quality Assurance.

3.3.1 Fuel Plates shall be inspected for the following:

(1) Fuel Core Density. The percent voids in the Fuel Cores of all the Fuel Plates shall be determined by the inspection procedure developed by the Fabricator (3.1(4)) and shall conform with 3.4.9.

(2) Cladding Thickness. All Fuel Plates shall be evaluated to the requirements of 3.4.10 by the procedures of 5.8. In addition, a minimum of one (1) randomly selected Fuel Plate per Lot shall be sectioned in accordance with Figure 1 for metallographic examination and evaluated to the Cladding thickness requirements of 3.4.10.

(3) Internal Defects and Bond Integrity. All Fuel Plates shall be visually and ultrasonically evaluated to the requirements of 3.4.4 by the procedures of 5.6. In addition, a minimum of one (1) Fuel Plate per Lot shall be metallographically examined to the requirements of 3.4.4.

(4) Core Configuration. All Fuel Plates shall be evaluated to the requirements of 3.4.3 by the procedure of 5.5.

(5) Surface Finish and Defects. All Fuel Plates shall be evaluated to the requirements of 3.4.5 by the procedures of 5.5.

(6) Cleanliness and Surface Contamination (Fuel). All Fuel Plates shall be evaluated to the requirements of 3.4.6 by the procedures of 5.9.

(7) Fuel Core Homogeneity. All Fuel Plates shall be evaluated to the requirements of 3.4.2 by the procedures of 5.3 and 5.4.

3.3.2 In-Process Controls. The In-Process Controls shall include, at least, the following:

(1) Evaluation of all Fuel Plates with regard to the requirements of 3.4.2 and 3.4.3 by the procedures of 5.3 and 5.5, respectively.

(2) Evaluation of all Fuel Plates with regard to the requirements of 3.4.4 and 3.4.5 by the applicable procedures of 5.6 and 5.7.

(3) Destructive analysis to the requirement of 3.4.4 and Cladding dimensions by sectioning, in accordance with Figure 1, a minimum of one (1) Fuel Plate per Lot, randomly selected.

3.4 Fuel Plate Requirements.

3.4.1 Composition. The Fuel Core shall conform with one of the compositions in Table I.

3.4.2 Homogeneity. A Fuel Core is considered homogeneous if the radiographic density does not exceed ±20% of the average density for all Fuel Core locations in any 0.080 inch diameter area, except ±30% is permitted in the Dogbone Area. If the density reading in any location is either too high or too low, four more density readings shall be obtained at the corners of a 1/2-inch square placed symmetrically about the anamolous reading. The average of the five readings, including the anamolous reading, shall be within ±20% or ±30%, whichever is applicable, of the average density for all Fuel Core locations. Boron homogeneity is satisfied when the boron content of any punching (Figure 1) does not vary by more than ±30% from the average of all punchings in the sample Fuel Plate.

3.4.3 Core Configuration. The outline of the Fuel Core shall be within the maximum and minimum of the core outline shown on EG&G Idaho Drawing 414489.

3.4.4 Internal Defects and Bond Integrity. A metallurgical bond with grain growth across a minimum of 50% of the Cladding/Picture-Frame interface is required. In addition, any visual or ultrasonic indications of nonbonds, voids, blisters, or laminations larger than 0.06 inch over the Fuel Core or 0.12 inch over the Picture Frame in the finally-sized Fuel Plate shall be cause for rejection.

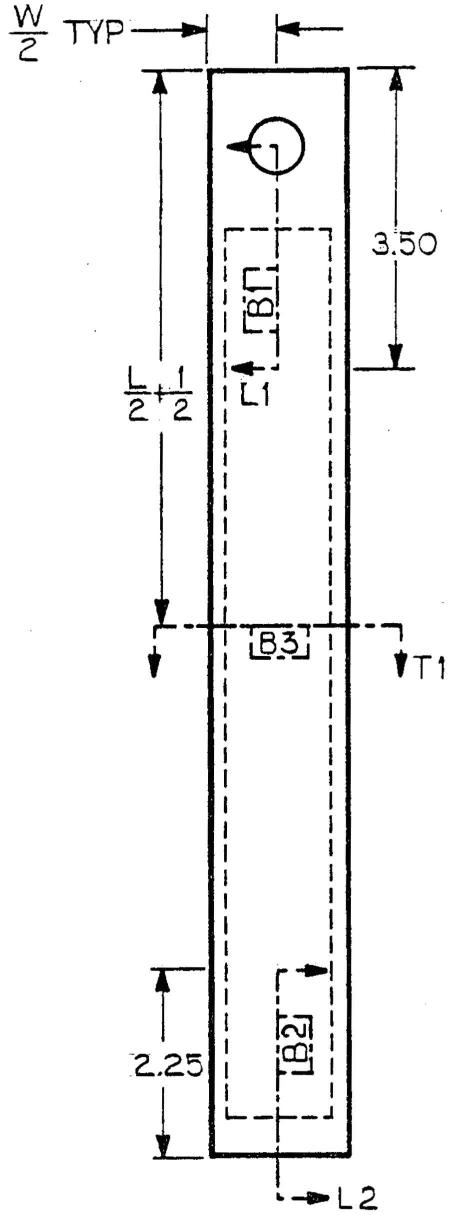


Figure 1. Fuel Plate sampling procedure for metallographic examinations. Boron punchings may also be obtained as shown for analysis.

TABLE I
FUEL CORE COMPOSITIONS

| Composition | $UAl_x$ Type* | g U-235 | mg B-10 |
|---|---|---|---|
| | | ±2% | ±4% |
| 1 | II | 5.90 | 16 |
| 2 | II | 6.65 | 18 |
| 3 | II | 7.40 | 20 |
| 4 | I | 5.35 | 14 |

* See Attachment VI.

3.4.5 Surface Finish and Defects. The finished Fuel Plates shall be free from pits, dents, scratches, and other areas of metal removed in excess of 0.005 inch in depth, except in the Dogbone Area. In this area, such depressions shall be limited to 0.003 inch in depth.

3.4.6 Cleanliness. All precautions shall be taken to maintain a high standard of cleanliness, in an area as defined in RDT F5-1T as a controlled work area, during fabrication, to ensure that no foreign materials or corrosion products are present in the finished Fuel Plates. The finished Fuel Plates shall be completely free of dirt, scum, scale, graphite, grease, oil, paint, ink, solder, silver, lead, mercury, thorium, chlorine, fluorine, and moisture. These precautions shall include:

(1) All metal chips, turnings, dusts, abrasives, weld spatter, scale and other particles shall be removed without destroying the continuity of the surfaces.

(2) All oil and grease shall be removed by the use of a degreasing agent and all surfaces, including all crevices, shall be thoroughly rinsed with distilled or demineralized water.

(3) Removal of transferable contamination from the finished fuel plate shall be accomplished by the procedure of 3.2.5.

3.4.7 Identification. Each finished Fuel Plate shall be identified by a number stamped or engraved as shown on EG&G Drawing 414489. The depth of the impression shall not exceed 0.006 inch. Positive identification shall be maintained relative to the complete fabrication history, including the plate lot, fuel blend, basic material lots, heat or melt, and manufacturing cycle.

3.4.8 Storage. All Fuel Plates that have received final cleaning shall be sealed in clean polyethylene bags while: (1) awaiting final assembly, (2) being transferred into storage, and (3) being maintained in storage. Any material exposed to contamination shall be reinspected to requirements of Section 3.4.6.

3.4.9 Percent Voids. The percent voids in the Fuel Cores shall be at least 4.00.

3.4.10 Cladding Thickness. The Fuel Plate Cladding thickness shall be 0.010 inch minimum throughout the Fuel Core area, measured from the fuel grain peak to the Fuel Plate surface except in the regions within 3-1/2 inches from the plate end having the hole and 2-1/4 inches from the other end. Within these regions the nominal cladding thickness shall be at least 0.008 inch. However, randomly distributed particles may penetrate the 0.008 inch cladding limit in accordance with a standard approved by the Purchaser.

4. MATERIALS OF CONSTRUCTION

The materials requirements for the components comprising the ELAF plates are as specified below:

4.1 Fuel Cores. The Fuel Cores shall consist of $UAl_x$ powder conforming with Attachment VI and $B_4C$ powder conforming with Attachment VII, dispersed in aluminum alloy powder conforming with Attachment III.

4.2 Picture Frames. Aluminum Plate Alloy 6061 per ASTM B-209 unclad or clad on both sides with alloy 1100. Thickness of the alloy 1100 cladding on each side shall be within the limits specified for the cover plate cladding (4.3). Maximum allowable boron content shall be 30 PPM.

4.3 Cover Plate. The fuel cladding shall be aluminum alloy 6061, ASTM B-209. Maximum allowable boron content shall be 30 PPM. Aluminum plate alloy 6061 clad on one side with alloy 1100. Each cover plate shall have an alloy 1100 clad thickness no less than 3 percent and a nominal maximum of 6 percent provided the three sigma limit does not exceed 7.5 percent. Compliance with the clad thickness requirements may be accomplished by a Fabricator-developed statistical sampling and analytical method approved by the Purchaser.

5. TEST AND INSPECTION REQUIREMENTS

The following tests and inspections shall be performed to ensure the product quality is in accordance with the requirements of this Specification. The supplier shall maintain a quality system in compliance with RDT F2-4T. Measurement equipment used for the tests and inspections required in this section shall be calibrated in conformance with RDT F3-2T.

5.1 Materials. A certificate of compliance or a certified material test report showing compliance with Section 4 shall be supplied for each lot of material used in the fabrication of the Fuel Plates. This certificate shall give the actual results of the chemical analysis for the Fuel Core materials. All materials shall be traceable to the Fuel Plates fabricated from these materials.

5.2 Composition. Conformance with 3.4.1 shall be established by Fabricator's certification of compliance with the approved procedure for controlling uranium and boron content required in 3.1(3).

5.3 Fuel Homogeneity. Compliance with the Fuel Core homogeneity requirements of 3.4.2 and Attachment II shall be determined by the radiographing of all Fuel Plates and an evaluation of the radiographs by calibrated (against a density wedge) densitometer measurements.

5.4 Boron Homogeneity. Conformance to the boron homogeneity requirements of 3.4.2 shall be established by Fabricator's certification of compliance with the approved procedure for preparing the Fuel Core powder. In addition, one Fuel Plate per Lot shall be analyzed for boron homogeneity using punchings obtained as shown in Figure 1.

5.5 Fuel Core Configuration. Compliance with the Fuel Core configuration requirements of 3.4.3 shall be determined by visual inspection of Fuel Plate radiographs. Visual radiograph inspections shall be performed without magnification on a light table having a light range of 450-600 foot-candles at the table surface and the area darkened to give a light range of 5-15 foot-candles at eighteen inches above the light table with radiographic film in place on the table.

5.6 Bond Integrity. Compliance with internal defect and bond integrity requirements of 3.4.4 shall be determined by ultrasonic examination and by performing a blister test on all Fuel Plates. The blister test shall be performed after hot-rolling, but before cold-rolling, by heating each plate to a temperature of 925 ± 15°F, holding at that temperature for one hour ±10 minutes, and cooling at a rate not to exceed 50°F/hr from the test temperature to 500°F.

5.7 Surface Finish and Defects. Compliance with surface finish and defect requirements of 3.4.5 shall be determined by 100% visual inspection of all plates without magnification.

5.8 Cladding Dimensions. Compliance with the reauiremets of 3.3.1(2) shall be established by Min-clad ultrasonic inspection of all Fuel Plates in the area 3-1/2 inches from the plate end having the hole and 2-1/4 inches from the other end using the purchaser-supplied Min-clad inspection scanner which is set to give indications of areas where the cladding is less than 0.008 inch in thickness. Acceptance of cladding less than 0.008 inch shall be based on a comparison of the Fuel Plate scan with a purchaser-supplied standard (section of ATR Fuel Plate 15-AB-039) scan. The inspection shall be performed at the normal mode (0.008-inch scan depth) using a 0.010-inch scan index. The standard shall be scanned just prior to the inspection of each lot. Acceptance criteria shall be:

5.8.1 Density of Indications. The density of indications (regions of the cladding less than 0.008 inch thick) shall be no greater in the Fuel Plate scan than in the standard scan.

5.8.2 Linear Alignment of Indications. The linear alignment of indications (the number of indications within a transverse strip 0.050 inch wide) in any region of the Fuel Plate scan shall not exceed that of the densest region of the standard scan.

5.9 Cleanliness. Compliance with the Fuel Plate cleanliness requirements of 3.4.6 shall be determined by visual inspection of 100% of the Fuel Plates. The surfaces of each Fuel Plate shall be counted for radioactive contamination. The alpha count shall be less than five (5) dpm (disintegrations per minute) per 100 square centimeters and the beta-gamma count shall be less than two hundred (200) dpm per 100 square centimeters.

5.10 Dimensional Inspection. Compliance with all dimensional requirements of the EG&G Idaho Drawing 414489 shall be determined by 100% inspection of the Fuel Plate. All dimensions of this specification shall apply at a temperature of 70 ± 5°F.

5.11 Voidage. Compliance with the voidage requirements of 3.4.9 shall be determined by measurements and calculations in accordance with Attachment I.

6. DATA AND RECORDS

The following data and records shall accompany the shipments:

(1) Certification of product compliance with the requirements of this Specification, including 5.2 and 5.4.

(2) Certification of material compliance with the requirements of Section 4, including any chemical and physical test result pertaining tereto.

(3) Dimensional data as required in 5.10.

(4) Individual Fuel Plate uranium and boron data including:

Supplier's core compact data sheets
Serial number with Batch identification
Fuel Core weight and composition number
U-235 content (grams)

Core void density
Boron-10 content (grams)
Type of $UAl_x$ (see Attachment VI)

(5) Transferable radioactive contamination count from each Fuel Plate as required in 5.9. The counting period, background, efficiency, and type of counter used shall be reported.

(6) List of all applicable waivers and deviations and related Fuel Plates.

(7) Radiographs as specified in 5.3 and 5.5.

(8) Photomicrographs as required in 3.3.1(2) and (3).

(9) Ultrasonic scans as specified in 5.6 and 5.8.

7. PREPARATION FOR DELIVERY

7.1 The Fuel Plates shall be separated for shipment according to composition and shall be wrapped in such a manner as to preclude physical damage during shipment.

7.2 The shipping container shall conform with Title 49 Code of Federal Regulation requirements.

7.3 Each shipping container shall be marked with a serial number and shall be accompanied by a shipping manifest which shows, as a minimum, the serial number on the container, the purchase order number, the net weight of the contents, and the total U-235 content in grams.

## 8. ACCEPTANCE INSPECTION

8.1 All materials, workmanship, and procedures shall be subject to inspection, examination, and test by the Purchaser, and to rejection by the Purchaser for noncompliance with the Specification at any time during manufacture and at any place where such manufacture is carried on. The Purchaser shall have the right to reject any one or more of the finished products for defects in any of the materials comprising the finished product which otherwise fail to meet the Specification. The final inspection shall include the packaging.

ATTACHMENT I

# DETERMINATION OF FUEL CORE VOIDAGE

## 1. SCOPE

This is a procedure for determining the volume percent voidage in uranium-aluminide Fuel Plate.

## 2. REQUIREMENTS

The percent voids in a fuel core shall be determined as follows:

$$V\% = \frac{V_c - V_{ct}}{V_c} \times (100\%)$$

where:

| | | |
|---|---|---|
| $V\%$ | = | percent voids in fuel core |
| $V_c$ | = | volume of fuel core |
| $V_{ct}$ | = | calculated theoretical core volume. |

The actual core volume shall be calculated as follows:

$$V_c = V_p - \frac{W_p - W_c}{d_{Al}}$$

where:

$V_p$ = volume of fuel plate

$W_p$ = weight of fuel plates

$W_c$ = weight of fuel core

$d_{Al}$ = density of aluminum used for plate cladding.

The theoretical core volume shall be calculated by the following methods:

$$V_{ct} = \frac{W_{UAl_x}}{d_{UAl_x}} + \frac{W_{Al}}{d_{Al}}$$

where:

$W_{UAl_x}$ = weight of $UAl_x$ powder used in the fuel core

$W_{Al}$ = weight of aluminum matrix powder used in the fuel core

$d_{Al}$ = density of aluminum matrix powder

$d_{UAl_x}$ = density of $UAl_x$ powder, based on diffraction analysis results (see Attachment VI, paragraph 4.5.3(3)).

ATTACHMENT II

# REQUIREMENTS FOR RADIOGRAPHING FUEL PLATES

## 1. SCOPE

This specification provides requirements for radiographing Fuel Plates, acceptable film quality and film identification.

## 2. REQUIREMENTS

A procedure must be written to specify the details for achieving acceptable Fuel Plate radiographs. The procedure shall include the requirements given in this specification.

2.1 Equipment Setup. The voltage shall be 100 kvp with a focal spot size of 5 mm maximum. The distance between the focal point and the Fuel Plate shall be 30 inches minimum. The focal point shall be centered laterally and longitudinally over the Plate or group of Fuel Plates.

2.2 Film.

2.2.1 The image outline shall be clear and sharp; the film shall be free of runs, streaks, scratches, blurs, and cassette defects that will affect the area covered by the Fuel Plates.

2.2.2 The film density of all points of the radiograph that correspond to Fuel Plate border locations outside the Fuel Core shall provide densitometer readings between 1.5 and 2.5. Film density as read over the nominal density standards shall provide densitometer readings between 0.9 and 1.5.

2.2.3 The film shall be an extreme sensitivity, extra fine grain, high contrast, double emulsion, industrial x-ray type (Kodak Type M or equivalent).

2.3 Film Identification. A system of identification of the film shall be provided which shall show as a minimum:

a. Plate Lot number

b. Plate size and serial number

c. Orientation of density standard

d. Density standard identification

e. Date of radiography

f. Kilovoltage, current and focal spot size

g. Type of film.

ATTACHMENT III

# SPECIFICATION FOR ALUMINUM POWDER FOR THE FUEL CORE MATRIX

## 1. SCOPE

1.1 This Specification covers the requirements for spherical aluminum powder to be used to adjust fuel density and to act as a binder in uranium-aluminide based reactor fuel.

## 2. APPLICABLE DOCUMENTS

Applicable portions of the following standards and specifications are explicitly specified in the body of and therefore form a part of the Specification.

American Society for Testing and Materials (ASTM)

| | |
|---|---|
| ASTM B 214 | Method of Test for Sieve Analysis of Granular Metal Powders |

## 3. REQUIREMENTS

3.1 Chemical Composition. The spherical aluminum powder shall be at least 98.5 wt.% free metallic aluminum (as determined using the test method described in MIL-A-81335). The limits on impurities shall be as specified in Table I and no single impurity element shall exceed 0.05% except those listed.

ATTACHMENT III

TABLE I

Limits on Impurities in Aluminum Powder wt.%

| Impurity | wt % |
|---|---|
| Cadmium | 0.002 Max |
| Lithium | 0.008 Max |
| Boron | 0.001 Max |
| Silicon + Iron | 0.25 Max |
| Zinc | 0.10 Max |
| Copper | 0.20 Max |
| $Al_2O_3$ | 0.7 Max |

3.2 Physical Configuration. The powder shall be smooth-surfaced and generally sperical. The powder shall also be dry (as specified for volatiles, and oil and grease in MIL-A-81335) and free from foreign material by visual examination as defined in 4.3 of this specification, unless otherwise approved by the Purchaser, 98.8% of the powder shall pass through a 100-mesh U.S. Standard sieve.

4. QUALITY ASSURANCE PROVISIONS

4.1 Sampling. The powder in each container shall be sampled and tested for compliance with the requirements of this Specification.

4.2 Acceptance Test. A chemical analysis shall be made on the samples from each container of powder to determine compliance with the requirements of 3.1. Noncompliance shall be cause for Rejection.

4.3 Examination. Powders from the samples taken as required in Section 4.1 shall be examined (at a magnification of at least 20 diameters) for compliance with the requirements of 3.2 for shape and cleanliness. Compliance with the particle size specified in 3.2 shall be determined by the test method given of ASTM B-214.

5. NOTES AND DATA

5.1 Quality Verification Test Results. Certified test results showing conformance with this specification shall be supplied to the Purchaser.

ATTACHMENT IV

# SPECIFICATION FOR ENRICHED U-METAL USED FOR SYNTHESIZING URANIUM ALUMINIDE

## 1. SCOPE

The specification covers uranium metal for use in fabricating dispersion-type nuclear Fuel Plates.

## 2. APPLICABLE DOCUMENTS

None.

## 3. TECHNICAL REQUIREMENTS

3.1 Physical Properties. The uranium metal shall be supplied in fracture (broken or sheated) pieces from the casting. The preferred nominal piece size is 150 g.

3.2 Isotopic Composition. The isotopic composition of the uranium metal shall be as follows:

| | |
|---|---|
| U-235 content | 93.0 ± 1.0 wt % of total U |
| U-238 content | 6.0 ± 1.0 wt % of total U |
| U-236 content | 0.700 max. wt% of total U |
| U-234 content | 1.2 max. wt % of total U |

3.3 Chemical Composition. The uranium content of the metal shall be 99.85% minimum. Individual impurities shall not exceed the following metal impurities shown in Table I.

ATTACHMENT IV

TABLE I

METAL IMPURITIES

| Element | Parts Per Million |
|---|---|
| Aluminum | 100.0 |
| Beryllium | 10.0 |
| Boron | 3.0 |
| Cadmium | 0.2 |
| Calcium | 50.0 |
| Carbon | 200.0 |
| Cobalt | 5.0 |
| Copper | 50.0 |
| Chromium | 50.0 |
| Iron + Nickel | 400.0 |
| Lithium | 10.0 |
| Magnesium | 50.0 |
| Manganese | 15.0 |
| Molybdenum | 100.0 |
| Lead | 5.0 |
| Silicon | 100.0 |
| Sodium | 25.0 |
| Hydrogen | 35.0 |
| Nitrogen | 100.0* |
| Oxygen | 100.0 |

*Nitrogen content of less than 50 ppm is desirable.

3.4 Cleaning. All uranium material shall be pickled to remove visually detectable slag, reductants, or oxides other than thin films of uranium oxides showing interference colors. The uranium is to be thoroughly rinsed with demineralized water to remove acid residues after pickling.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Testing. The supplier shall be responsible for performing all tests and inspections required by this specification, except the oxygen, nitrogen and hydrogen analyses, which shall be performed by the Fabricator.

4.2 Sampling. The uranium metal from each lot shall be sampled and tested in accordance with the requirements of 4.3.

4.3 Acceptance Tests. The following tests shall be conducted on all lots of material.

4.3.1 Isotopic Composition. The isotopic composition of each lot of uranium metal shall be determined by mass spectrographic analysis or equivalent method.

4.3.2 Chemical Composition. The chemical composition and impurities shall be determined on each lot of material. The results shall be in conformance with 3.3.

4.4 Certified Reports. Certified reports on uranium starting stock showing conformance to this Specification shall be obtained and supplied to the Purchaser before the material is used in fabricating $UAl_x$ fuel.

ATTACHMENT V

# SPECIFICATION FOR ALUMINUM STOCK USED FOR SYNTHESIZING URANIUM ALUMINIDE

## 1. SCOPE

This specification covers the aluminum stock used in the preparation of uranium aluminide ($UAl_x$).

## 2. APPLICABLE DOCUMENTS

None.

## 3. TECHNICAL REQUIREMENTS

3.1 Physical Properties. The aluminum metal shall be in rod, sheet or plate form.

3.2 Chemical Composition. The aluminum content of the metal shall be 99.95% minimum.

3.3 Cleaning. All aluminum material shall be pickled and/or degreased to remove visually detectable oxides or other surface deposits. The aluminum is to be thoroughly rinsed with demineralized or distilled water to remove pickling agent residues after pickling.

## 4. QUALITY ASSURANCE PROVISIONS

The results of all tests shall be recorded as quantitative data.

ATTACHMENT V

4.1 Sampling. The aluminum metal from each lot used in the preparation of $UAl_x$ shall be sampled and tested in accordance with the requirements of 4.2.

4.2 Acceptance Tests. The impurities shall be determined on each lot of material. The results shall be in conformance with Paragraph 3.2.

4.3 Certified Reports. Certified reports on aluminum starting stock showing conformance to this Specification shall be obtained and submitted to the Program Manager before this material is used in fabricate fuel.

ATTACHMENT VI

# SPECIFICATION FOR URANIUM-ALUMINIDE POWDER FOR ELAF FUEL PLATES

## 1. SCOPE

This Specification covers uranium-aluminide ($UAl_x$) powder for use in fabricating dispersion-type nuclear Fuel Plates, and its manufacture.

1.1 Classification. The uranium-aluminide powder shall be of the following types, as specified (see paragraph 6.2):

Type I - Predominately $UAl_3$ (∿71 wt.% U)

Type II - Predominately $UAl_2$ (∿ 80wt.% U)

## 2. APPLICABLE DOCUMENTS

The following documents form a part of this Specification except as modified by this Specification. Where there is a conflict between the documents cited and the latest revision thereof, the Supplier shall notify the Purchaser of the conflict and use the latest revision unless otherwise directed by the Purchaser.

| | |
|---|---|
| ASTM B 214 | Method of Test for Sieve Analysis of Granular Metal Powder |
| ASTM B 212 | Test for Apparent Density of Metal Powders |
| ASTM B 213 | Test for Flowrate of Metal Powders |

ATTACHMENT VI

| | |
|---|---|
| ASTM D 480 | Aluminum Powder and Paste Sampling and Testing |
| IDO-14605 | Annual Report of Division Chemistry Analytical Branch for 1962 |

3. REQUIREMENTS

3.1 Materials. The uranium isotopic composition or enrichment values of the uranium-aluminide shall be reported to the Purchaser and shall be such to comply with this Specification. The aluminum alloy composition shall be reported to the Purchaser and shall comply with this Specification.

3.2 Composition.

3.2.1 Uranium Isotopic Composition. The uranium isotopic composition shall be defined as follows:

At the 95% confidence level, the uranium-aluminide shall have the following isotopic composition.

| | |
|---|---|
| U-235 Content | 93.0% $\pm$ 1.0 wt.% of total U |
| U-238 Content | 6.0% $\pm$ 1.0 wt.% of total U |
| U-236 Content | 0.700 max. wt.% of total U |
| U-234 Content | 1.2 max. wt.% of total U |

3.2.2 Chemical Composition. At the 95% confidence level, the uranium content of the uranium-alumunide powder shall be: 71.0 $\pm$ 2.0 wt.% for Type I and 80.0 $\pm$ 1.0 wt.% for Type II. The balance of the chemical composition shall be aluminum as specified in Section 3.2.2(1). A

ATTACHMENT VI

(1) Uranium-Aluminide Impurity Content. The uranium-aluminide shall contain no more than the following amounts of individual impurities.

| Element | Maximum Allowable Amount |
|---|---|
| Oxygen | 0.60 wt.% |
| Carbon | 0.18 wt.% |
| Nitrogen | 0.045 wt.% |
| Hydrogen | 0.020 wt.% |
| Nonvolatile matter, minimum | 99.0 wt.% |
| Easily extracted fatty and oily matter, maximum | 0.2 wt.% |

The total impurity content shall not exceed the equivalent boron content (EBC) of 30 parts per million on a weight basis relative to uranium.

The EBC of each element shall be calculated by the following formula:

EBC (impurity) = EBC ppm x impurity ppm

The following listed elements shall be included in the calculation of the EBC. The Supplier shall make and report impurity EBC analyses of the uranium-aluminide powder for the elements listed below.

ATTACHMENT VI

## BORON EQUIVALENTS FOR IMPURITIES IN URANIUM

| Impurity | EBC PPM |
|---|---|
| Barium | 0.000122 |
| Beryllium | 0.000015 |
| Boron | 0.999999 |
| Calcium | 0.000158 |
| Cadmium | 0.325097 |
| Chromium | 0.000799 |
| Cobalt | 0.009239 |
| Copper | 0.000868 |
| Iron | 0.000672 |
| Lead | 0.000011 |
| Magnesium | 0.000040 |
| Manganese | 0.003443 |
| Molybdenum | 0.000403 |
| Nickel | 0.001122 |
| Phosphorus | 0.000087 |
| Silicon | 0.000066 |
| Silver | 0.008236 |
| Tin | 0.000072 |
| Tungsten | 0.001496 |
| Vanadium | 0.001406 |
| Zinc | 0.000241 |
| Zirconium | 0.000029 |
| Samarium | 0.524575 |
| Europium | 0.433973 |
| Gadolinum | 4.19458 |
| Dysprosium | 0.097064 |

3.3 Physical Properties.

3.3.1 Particle Size. The uranium-aluminide powder shall be -100, +325 U.S. Standard mesh particles. However, a blend may contain up to 25 wt.% of -325 U.S. Standard mesh particles.

3.3.2 Crystalline Constituents. The finished ground and sized uranium-aluminide powder shall contain at least 65 wt.% $UAl_3$ if Type I or 70 wt. % $UAl_2$ if Type II. A

3.3.3 Powder Density. Bulk and powder density values will be determined and provided for information purposes only.

4. QUALITY ASSURANCE PROVISIONS

4.1 General Quality Assurance Provisions.

4.1.1 Performance of Inspections and Tests. Unless otherwise specified in the procurement documents, the Supplier is responsible for the performance of all inspections and tests to the requirements of 3.2 and 3.3, prior to submission of the acceptance sample for Purchaser inspection and acceptance.

4.1.2 Results of Examinations and Tests. Unless otherwise specified, the Supplier may utilize his own facilities or any commercial laboratory acceptable to the Purchaser. Results of all examinations and tests performed under the Quality Assurance Section shall be complete and supplied to the Purchaser.

4.2 Classification of Tests. All tests required herein for product assurance are classified as acceptance tests, for which necessary sampling techniques and methods of testing are specified in this section.

4.3 Inspection Provisions.

4.3.1 Batch. The amount of uranium-aluminum intermetallic $UAl_x$ powder mixture which is handled as a unit or traceable to a common step. Each production quantity which is blended together to form the Batch will have the same chemical and physical characteristics.

4.3.2 Sampling. A representative sample of uranium-aluminide shall be taken by the Supplier from each batch for the purpose of determining isotopic composition, chemical and physical properties.

4.4 Inspection. Unless otherwise specified in the procurement documents, all samples shall be analyzed to determine compliance with the requirements of this Specification. Any Batch that does not conform to this Specification, as determined by analysis of the sample (4.3.2), shall be rejected.

4.5 Tests.

4.5.1 Isotopic Composition. The isotopic composition of the uranium-aluminide shall be determined for compliance with paragraph 3.2.1. The test method shall be by mass spectrographic analysis or equivalent.

4.5.2 Chemical Composition. The uranium and aluminum content of the uranium-aluminide powder shall be determined for compliance with paragraph 3.2.2.

(1) Impurity Content. The impurity content of the uranium-aluminide powder shall be determined for compliance with the requirements of 3.2.2(1). Analysis shall be performed for all of the elements listed in this section, both metallic and nonmetallic. Samples shall be as specified in 4.3.2. If the presence of elements other than

those specified is suspected because of the raw materials used, the manufacturing process used, or, if discovered in the course of routine analysis, further analysis shall be made to determine that the equivalent boron content, EBC, does not exceed the specified level of 30 ppm. Test methods for nonvolatile matter and easily extracted fatty and oily matter are given in ASTM D 480.

4.5.3 Physical Properties.

(1) Particle Size. To assure adequate distribution of particle size range, the uranium-aluminide powder shall be tested for compliance with 3.3.1 in accordance with ASTM B 214.

(2) Crystalline Constituents. The crystalline constituents of the uranium-aluminide powders shall be determined by x-ray diffraction analysis.

(3) Fuel Density. The bulk fuel density shall be determined in accordance with ASTM B 212. The absolute particle density shall be determined by helium displacement as described in IDO-14605, page 91. (This document is available from Office of Technical Services, U.S. Department of Commerce, Washington 25, D.C.)

(4) Flow Rate. The flow rate of the fuel powder shall be determined in accordance with ASTM B 213. The drying step called for in the procedure shall be conducted under vacuum ($10^{-3}$ TORR or better) instead of air.

4.6 Reports of Tests. The following certified test reports shall be provided by the supplier and approved by the Purchaser prior to use.

(a) Analytical results on raw materials used to prepare uranium-aluminde.

(b) Analytical results on finished ground and sized $UAl_x$ fuel powder. These results shall include (1) uranium content, (2) aluminum content, (3) impurity content, (4) calculated equivalent boron content of impurities, (5) isotopic composition, (6) amount of nonvolatile matter, and (7) the amount of easily extracted fatty and oil matter.

(c) The results of physical property determinations made on the finished ground and sized $UAl_x$ fuel powders. These results shall include (1) x-ray diffraction results, (2) bulk density, (3) particle density, (4) sieve analysis, and (5) flow rate.

4.6.1 Certified Reports. Certified reports of the uranium and aluminum starting materials and uranium-aluminide powders which the Supplier accepts shall be kept complete and made available to the Purchaser.

5. PREPARATION OF DELIVERY

5.1 Packaging. Packaging of the uranium-aluminide shall be in accordance with applicable DOE and DOT regulations covering this type of material and as specified in the procurement documents (see Section 6.2).

5.2 Marking. In addition to DOE marking requirements for this type of material, the outside of each container shall be marked clearly with the following information:

a. Material type

b. Number, date of this Specification

c. Manufacturing Lot number

d. Net weight of uranium-aluminide ($UAl_x$) and calculated weights of uranium and U-235.

e. Purchase order number.

6. NOTES AND DATA

6.1 Quality Verification Test Results. Six (6) copies of the certified test results (see Section 4.6) shall be submitted to the Purchaser prior to the shipment of any material. One copy of such reports shall accompany the shipment as a packing slip. Included in the test results must be sampling, analytical and quality control procedures; a statement as to the estimated accuracy and precision of the test values and development and production data in support of the accuracy and precision estimate.

6.2 Ordering Data. The procurement documents shall specify the following:

a. Title, number, date of this Specification

b. Type of uranium-aluminide powder (see 1.1)

c. Percent of U-235 enrichment (see 3.2.1)

d. Packaging requirements (see 5.1).

6.3 Accountability. Forms for the transfer of the accountability and the financial responsibility for the nuclear material shall be submitted prior to or at the time of shipment of any material.

ATTACHMENT VII

# SPECIFICATION FOR BORON CARBIDE POWDER FOR ELAF PLATES

1. SCOPE

1.1 Scope. This Specification covers the requirements for a high boron grade of boron carbide powder for use in nuclear reactor fuel.

2. APPLICABLE DOCUMENTS

2.1 Standards, Specifications, Drawings and Attachments. The following documents form a part of this Specification except as modified by this Specification.

SPECIFICATIONS

American Society for Testing and Materials (ASTM)

| | |
|---|---|
| ASTM B 214 | Method of Test for Sieve Analysis of Granular Metal Powders |

3. REQUIREMENTS

3.1 Chemical Composition. The boron carbide ($B_4C$) covered by this Specification shall have a chemical composition within the limits shown in Table I.

3.2 Particle Size. All of the boron carbide powder shall pass through a 325-mesh U.S. Standard sieve.

ATTACHMENT VII

TABLE I
Chemical Compositon

| Element | Concentration Min. | Max. | |
|---|---|---|---|
| B-10 | 14 | | wt% |
| Boron (total) | 76.5 | | wt% |
| Carbon | 19 | 22 | wt% |
| Boron plus carbon | 98 | -- | wt% |
| $B_2O_3$ | -- | 0.3 | wt% |
| Soluble boron | | 0.5 | wt% |
| Boron/carbon atom ratio* | -- | 4.75 | |
| Iron | | 0.5 | wt% |
| Aluminum | | 0.2 | wt% |
| Calcium | | 0.25 | wt% |
| Magnesium | | 0.05 | wt% |
| Moisture | | 0.02 | wt% |

*B/C atom ratio = $\text{wt}\ \frac{(\text{total B - Soluble B})}{10.81} - \frac{\text{Wt C}}{12.01}$

$= \text{Wt}\ \frac{(\text{total B - Solu B})}{\text{Wt carbon}} \times 1.111$

4. QUALITY ASSURANCE PROVISIONS

4.1 Test Results. The results of all tests shall be recorded as quantitative data.

4.2 Sampling. The powder from each lot used shall be tested for conformance with the requirements of the Specification.

4.3 Acceptance Tests. The following tests whall be conducted on all lots. Noncompliance shall be cause for rejection.

4.3.1 Isotopic Composition. The isotopic composition of the $B_4C$ shall be determined by mass spectrographic analysis or a method approved by the Purchaser. The B-10 isotope concentration shall be in conformance with 3.1.

4.3.2 Chemical Composition. The chemical composition and impurities shall be determined by standard analytical techniques. The results shall be in conformance with the requirements of 3.1.

4.3.3 Particle Size of Powdered Material. The particle size of the material shall be determined in accordance with the requirements of ASTM B 214-66. The results shall be in accordance with 3.2.

4.3.4 Certified Reports. Certified reports of results showing conformance with this shall be obtained and submitted to the Purchaser before this material is used to fabricate fuel.